3.0 INSTRUMENTATION

BACKGROUND

The Instrumentation Action Team (Instrumentation AT) has the responsibility of fostering collaboration between individual HCF instrumentation efforts with the overall goal of combining with the Forced Response and Component Analysis ATs to better determine alternating stresses to within 20%. The Instrumentation AT provides technical coordination and communication between active participants involved in HCF measurement, sensor, data processing, and engine health monitoring technologies. Technical workshops have been organized on at least an annual basis and summaries of these workshops are disseminated to appropriate individuals and organizations. The Chair, Co-Chair, and selected Instrumentation AT members meet as required (estimated quarterly) to review technical activities, develop specific goals for instrumentation and engine health monitoring programs, and coordinate with the TPT and IAP. The Chairman (or Co-Chair) of the Instrumentation AT keeps the TPT Secretary informed of AT activities on a frequent (at least monthly) basis. This AT includes members from government agencies, industry, and universities who are actively involved in instrumentation technologies applicable to engine HCF. The team is to be multidisciplinary with representatives from multiple organizations representing several component technologies as appropriate. The actual membership of the AT may change in time as individuals assume different roles in related projects.

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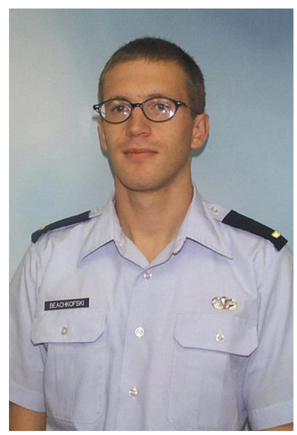

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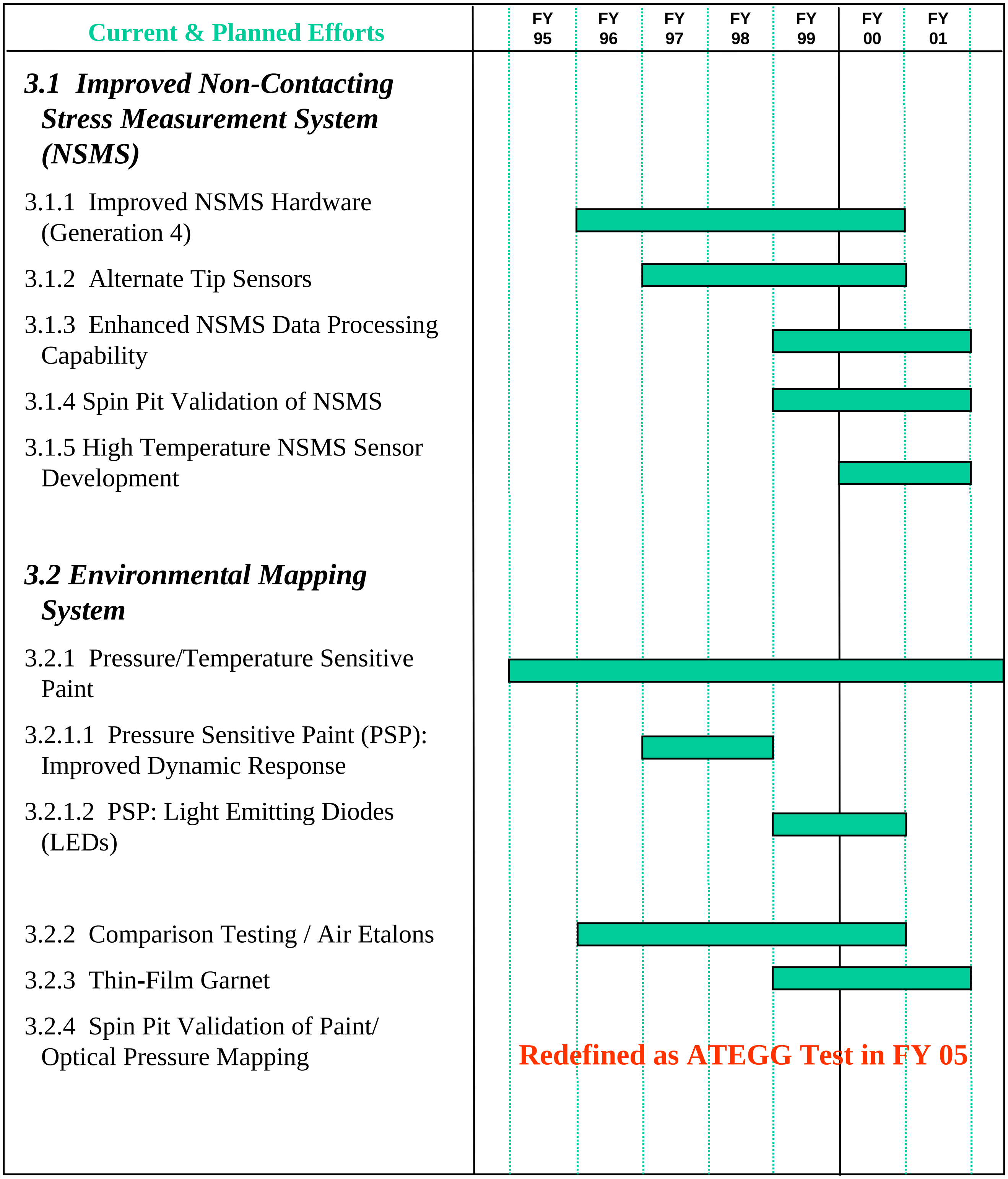
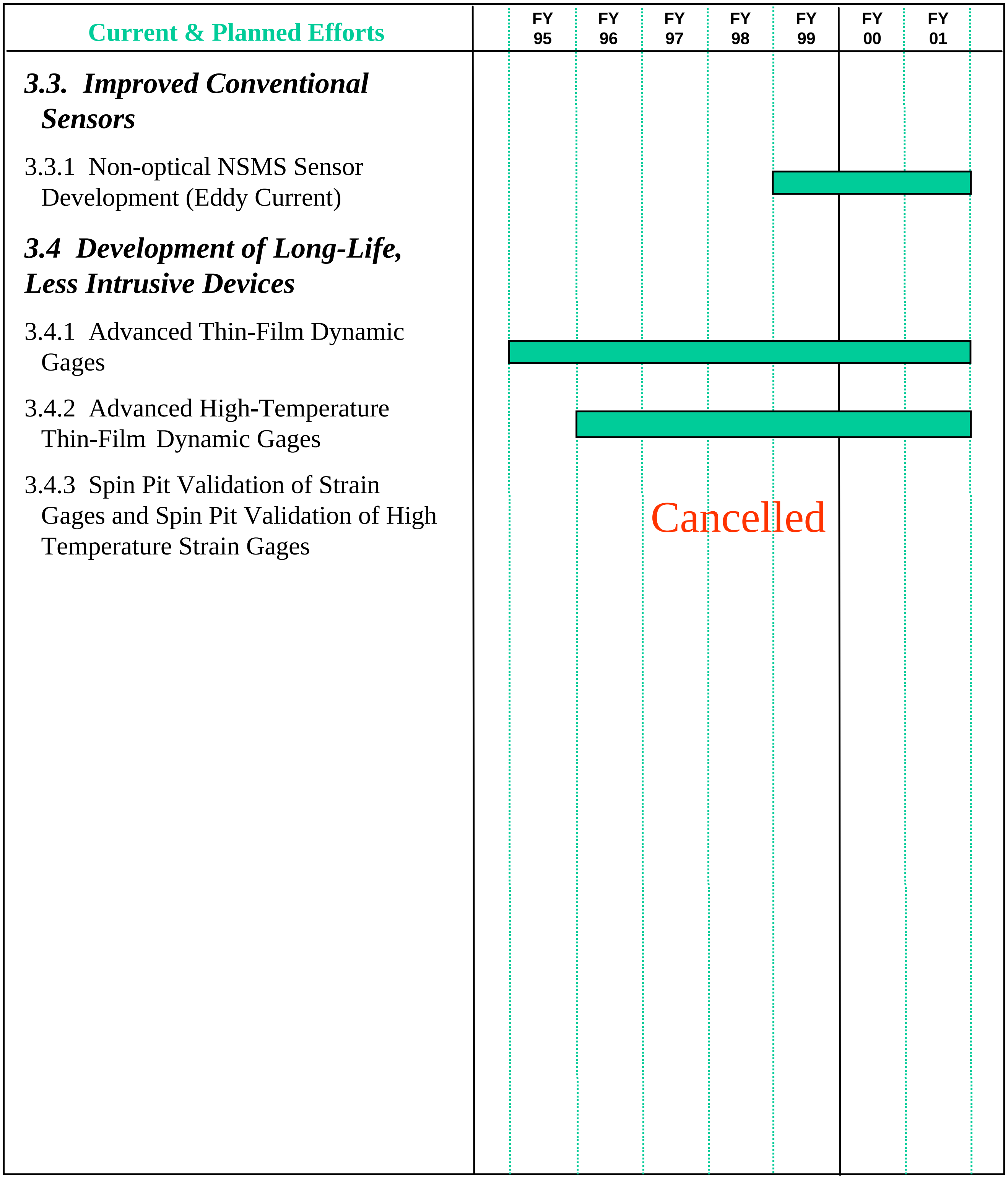
INTRODUCTION

The following pages summarize the schedules, backgrounds, and recent progress of the current and planned projects managed by this action team.

Instrumentation Schedule



Instrumentation Schedule *(Cont.)*



3.1 Improved Non-Interference Stress Measurement System (NSMS)

To date, prediction of aerodynamic forcing functions has been difficult or impossible due to lack of Computational Fluid Dynamics (CFD) fidelity, structural modeling accuracy, instrumentation effects, and insufficient characterization of instrumentation installation effects. The purpose of the projects described below is to develop an advanced generation NSMS (Fig. 23) capable of detecting simultaneous integral-order modes with a 5X improvement in accuracy, and to provide the ability to accurately convert the measured tip deflection to a dynamic stress map.

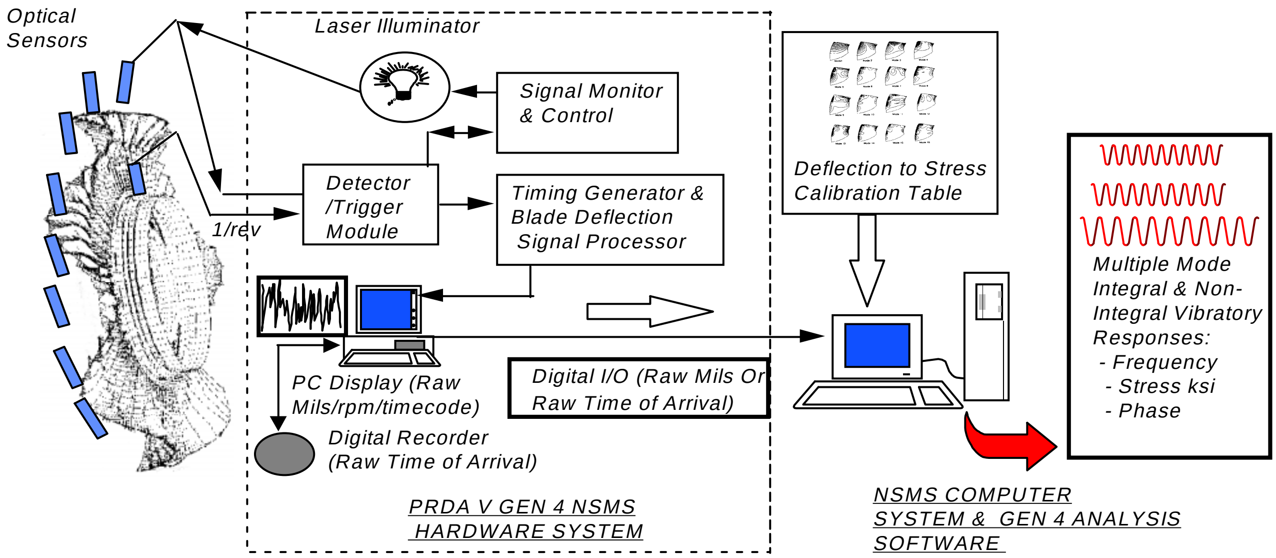


FIGURE 23. Next-Generation NSMS Overview

3.1.1 Improved Non-Interference Stress Measurement System (NSMS) Hardware (Generation 4)

FY 96-00

Recent Progress: Progress has been made on all four major subsystems of the NSMS hardware: Electro-Optics, the Blade-Deflection Signal Processor (BDSP), the Optical Probe, and the Blade Timing Generator. NSMS hardware also fared very well both in conventional simulated altitude testing as well as flight testing.

Electro-Optic Development:

This effort has been subcontracted to Arnold Engineering Development Center (AEDC). A manpower limitation that occurred within the existing project team made this necessary. Existing designs, documentation and materials from the Electro-Optics Task were delivered to AEDC. AEDC personnel are rapidly gaining familiarity with the various aspects of the design and are proceeding.

Blade-Deflection Signal Processing (BDSP):

Design and layout of the enhanced trigger board is complete and the board has been ordered. Nearly every electronic part has been received for 24 channels of detectors, lasers, and trigger boards. Major parts remaining to be ordered are packaging and power supplies. Single-mode lasers have been received and shipped to OZ Optics for installation in fiber-coupling devices. The photosensitivity of the detector has been redefined to match response of current NSMS Generation 4. This will enable our detectors to respond to reflected light signals in the 100nW to 20μW range. Required design changes are complete, but detector board layout must be updated. Also, temperature compensation has been added to the detector bias circuit. Software for interface from BDSP to Electro-Optics has been received and installed.

Optical Probe Development:

A prototype custom-designed connector for coupling the sensor output to the Photo-Detector was fabricated and delivered to AEDC. It will accept an off-the-shelf optical filter. Lab tests will be initiated to determine the minimum size and quantity of receive fibers for the five-lens optical head. Size and quantity (fibers) directly impact the cost of the optical extension cable (fiber core size drives cost).

Blade Timing Generator Development:

To date, we have a Master Clock and seven Timer cards that appear to work as designed. Testing of the prototype Master Clock and Timer cards will be completed 1Q FY00. The circuits will be revised as necessary and new boards procured. If the fixes are minor, the full set of circuit boards (24 channels) will be procured. We expect to receive the Blade Timing Generator chassis by 1Q FY00. Overall, preliminary designs have been completed and prototyping and bench testing of major subsystems are well underway. The high-temperature line-probe technology was demonstrated in F119 high-pressure compressor (HPC) for over 100 hours. The multi-lens configuration (low temperature, shown below) is being used extensively in current JSF, F119 ISR, and ATEGG applications, and was used in the PW2037 (F117) and PW4000 low-pressure compressor (LPC) and HPC NSMS applications at Pratt & Whitney.

The line probe has demonstrated superiority over conventional probes, as it is capable of measuring multiple-occurring synchronous and non-synchronous vibratory modes that yield greater than 1 mil peak-to-peak component deflections. Figure 24 is an artist's conceptualization of the probe. The line is created by five optical lenses. The current configuration is capable of operating at 350 °F continuously and 500 °F for a limited time. Work continues to increase the temperature capability of the system. The Gen 4 probe will be capable of continuous operation at 650 °F.

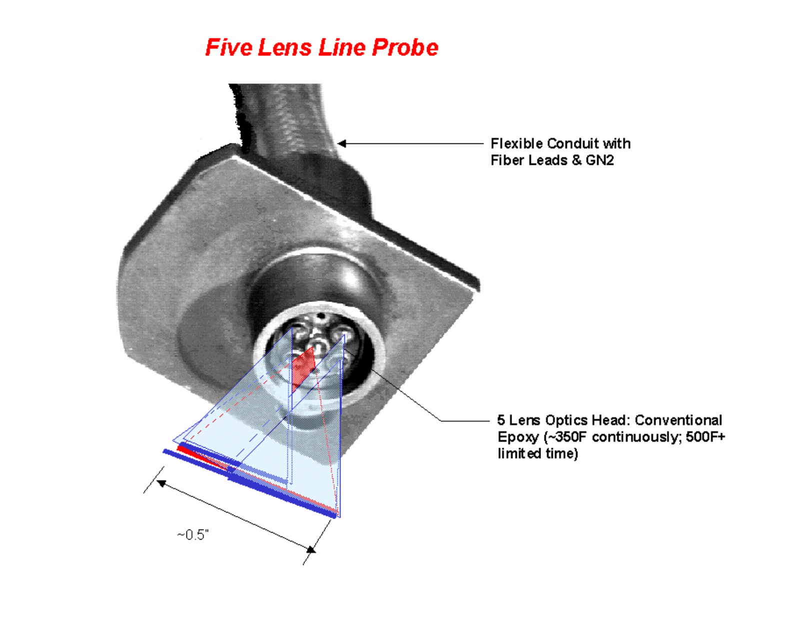


FIGURE 24. Five-Lens Line Probe

NSMS Flight Program:

An NSMS flight program has been conducted on an F100-220 redesigned first-stage high-pressure compressor blade in an F-15 aircraft at Edwards Air Force Base (EAFB). The F100-220 first-stage high-pressure compressor blade was recently redesigned and is currently undergoing design validation substantiation testing. In addition to conventional simulated altitude testing in a laboratory test cell at Arnold Engineering Development Center (AEDC), a flight test program has been conducted to verify flutter-free operation in an F-15 aircraft at Edwards Air Force Base (EAFB).

For testing at AEDC, the first, second and third stages of the high-pressure compressor (HPC) were instrumented with conventional strain gages and NSMS optical sensors. NSMS sensors utilized in the AEDC testing were adaptations of optical line sensors currently being developed under a contract related to the High Cycle Fatigue Program. All three stages were heavily instrumented with NSMS sensors (eight or nine probes per stage) to provide measurement of flutter and multiple-occurring integral-order vibratory modes. NSMS data quality from the AEDC testing was excellent, and comparison with conventional strain-gage data is underway.

Three probes were installed, including one backup and two probes required for full analysis of any flutter events. The optical element of the sensor was a bundle of seven aluminum-jacketed 100-µm-diameter core optical fibers. Figures 25 and 26 show the sensor head and the lead egress from the area of the unison ring. These sensors were capable of continuous operation at 750 ^{o}F (up to 900 ^{o}F for a limited time) without cooling.

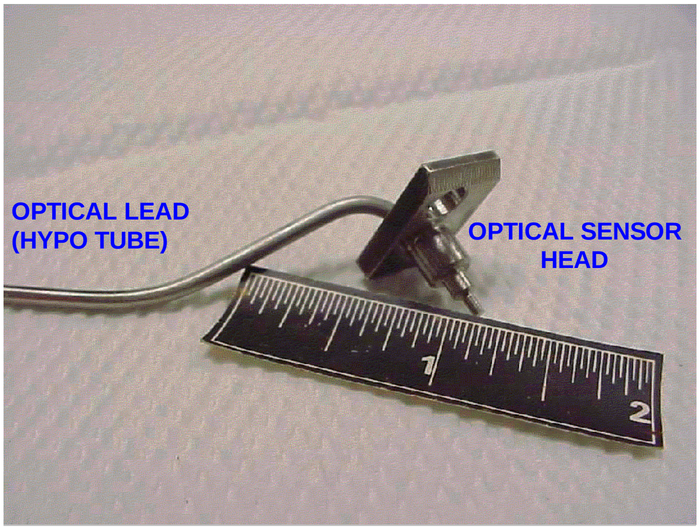


FIGURE 25. F100-220 First-Stage High Compressor NSMS Flight Probe

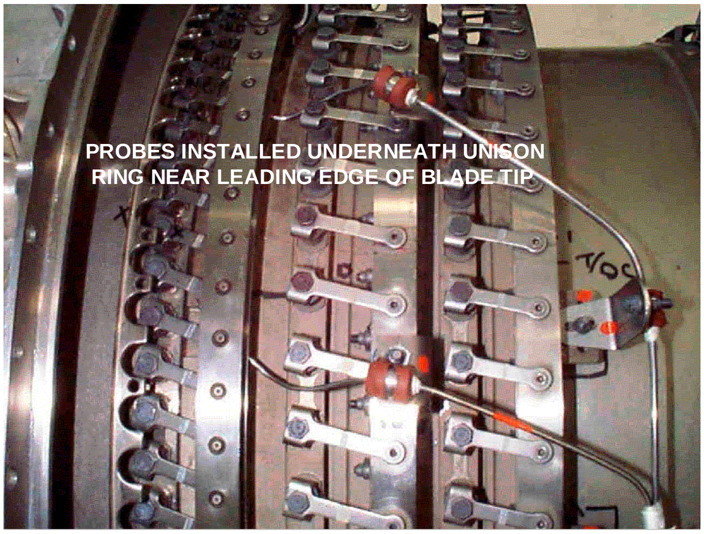


FIGURE 26. F100-220 First-Stage High Compressor NSMS Optical Probe Lead Routing

An existing multichannel custom-designed Electro-Optical signal-conditioning module provided illumination and optical-to-analog electrical signal conversion for the sensors. Illumination was provided by ¼-watt laser diodes (~850nm wavelength), one per sensor. Avalanche photo detectors were used to produce the electrical signals. Additionally, the module provided signal conditioning for the 1/rev variable reluctance sensor. This system was custom designed by the engine manufacturer and built for a previous flight test of the F100-220 third-stage low-pressure compressor conducted on the same aircraft in 1995 and 1997. Aircraft avionics cooling air was used to maintain a safe operating temperature in the Electro-Optics module.

During flight, NSMS data were recorded on the aircraft's special instrumentation magnetic tape recorder. During specific flights designated for NSMS data, the recorder was run at 30 ips to provide a bandwidth of 125KHz for the NSMS sensor signals. Data from the three NSMS optical 1/blade sensors and the 1/rev magnetic sensor were recorded along with other parameters and an IRIG time code signal (for time correlation of data). All three sensors provided high-quality data throughout the flight test program.

Post-flight, data tapes were screened to search for flutter events using the engine manufacturer's Flutter Monitor. Preliminary results indicate the blade was flutter-free under all flight conditions where NSMS data were collected.

More-detailed analysis is planned for the near future at the engine manufacturer's home facility using an NSMS computer-based system. With the high-quality data obtained from all three probes and a good 1/rev signal, the analysis for the presence and characterization of any non-integral vibratory blade responses should be very complete. Additionally, even with only three sensors, it may also be possible to glean a considerable amount of information on the fundamental resonant responses under actual flight conditions.

The ability to validate blade vibratory responses during actual flight reduces the probability that HCF-susceptible blades will be placed into production. Three NSMS flight programs have been conducted in this specially outfitted F-15 aircraft (77-139) over the past several years on F100-220 engines to aid in HCF blade failure investigations and/or to validate blade redesigns. Currently, it is undergoing major overhaul. It is anticipated that the capability to fly and collect NSMS data will be retained in the aircraft when it returns to flight test service.

Participating Organizations: Pratt & Whitney, Honeywell Engines and Systems, Arnold Air Development Center (AEDC)

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3.1.2 Alternate Tip Sensors

FY 97-00

Background: As part of the Fourth Generation NSMS development effort, a study of alternate (i.e., non-optical) NSMS sensors has been initiated. The motivation for this study arises principally from problems associated with applying optical sensors, namely installation complexity and susceptibility, to optical contamination. These problems are of paramount importance in flight test and engine health monitoring applications (but are of less concern in ground-based engine testing). A sensor capability specification was prepared with input from the members of the Fourth Generation NSMS design team. This sensor specification defines the requisite characteristics of sensors to be used for engine health monitoring and Third and Fourth Generation NSMS applications. This sensor specification was used as a basis for evaluating the suitability of alternative sensor technologies for Fourth Generation NSMS applications.

Recent Progress: Over the past year, the literature search to identify alternate NSMS sensor technologies suitable for NSMS applications has continued. A full report will be written on this subject in fiscal year 2000.

Participating Organizations: Rolls Royce Allison

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3.1.3 Enhanced Data Processing Capability for Generation 4 & 5 NSMS Development

FY 99-01

Recent Progress: A Design Review was conducted on in May 1999 in Albuquerque. All of the tasks were reviewed. However the focus was on software documentation. No major problems were uncovered. Arnold Air Development Center (AEDC) participated in the review. Work on the Blade Timing Generator (BTG) and Blade Deflection Signal Processing (BDSP) is proceeding well. Production version BTG cards are being fabricated. The software documentation is complete, and sign off has occurred.

Participating Organizations: Arnold Air Development Center (AEDC)/Sverdrup, Honeywell Engines and Systems, Rolls Royce Allison

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3.1.4 Spin-Pit Validation of NSMS
FY 99-01

Recent Progress: Discussions with the Navy are underway to incorporate NSMS into its spin-pit test instrumentation. In preparation, NSMS Generation 3 light probes have been loaned to the Naval Postgraduate School (NPS). The research effort is focused on a joint project to evaluate eddy-current excitation and to develop measurement techniques and expertise required in full-scale HCF-related spin tests. Hood Technology Corporation (HTC) will conduct excitation tests in a research-dedicated spin pit facility at NPS. The test article, an F119 integrally bladed rotor (IBR), was received from Pratt & Whitney early in early August. Discussions were held on the design of possible test configurations, and two candidate arrangements will now be detailed.

Effort has concentrated, very successfully, on the development of an HCF measurement capability. The power supplies for a four-channel laser-light probe system were completed, and the probes were installed on and used to observe rotor blade vibrations in a large, low-speed multistage compressor. After verifying the system using an oscilloscope, two probes were used with one HTC "BVM Interface Board" and one National Instruments PCI Counter Board, to record time-of-arrival (NSMS) data. Labview software, also from HTC, was used in the acquisition. Data reduction using Matlab is planned. A second interface board will allow the simultaneous acquisition from all four probes.

Preliminary testing in the spin pit facility is continuing using a larger (M1 turbine) rotor. The goals are to refine shaft orbital displacement measurements to enable in-situ trim balancing, and to demonstrate unsteady strain measurement capability. The order was placed for a 16 (unsteady)/32-channel VXI/PC high-speed data acquisition system for strain gages. The machining of hardware to improve the 1/rev trigger sensor was completed. Also, components of an automatic speed-control system for the facility were delivered from Barbour-Stockwell. Installation of the automatic system will be scheduled when the present test goals are achieved.

Participating Organizations: Air Force Research Laboratory (AFRL), Navy

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3.1.5 High-Temperature NSMS Sensor Development

FY 00-01

Background and Plans: NSMS sensors do not currently have the high-temperature capability necessary to adequately monitor high-pressure turbine (HPT) blades in the engine environment. The purpose of the project is to develop high-temperature probes to interface with the existing Generation 4 NSMS signal processing hardware. Light probes for ground test applications and Eddy Current probes for Engine Health Monitoring will be investigated. A major emphasis of this project will be balancing the increased temperature capability with sensor life and accuracy.

Participating Organizations: Air Force Research Laboratory (AFRL)

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3.2 Environmental Mapping System

To date, prediction of aerodynamic forcing functions has been difficult or impossible due to lack of Computational Fluid Dynamics (CFD) fidelity, lack of structural modeling accuracy, instrumentation effects, and insufficient characterization of instrumentation installation effects. The purpose of the tasks described below is to develop an optical pressure and temperature measurement system to non-intrusively measure the dynamic pressure and temperature distribution over the surface of the blade.

3.2.1 Pressure/Temperature Sensitive Paint (PSP/TSP)

FY 95-02

Recent Progress: Over the past year, extensive work has been done to improve the processing of PSP images. The extremely labor-intensive post processing will soon be completely automated, saving hundreds of man-hours. To improve the paint formula, we re-engineered the binding matrix supporting the luminophores. We also researched other illumination techniques and developed a new reference paint that would remove one time-consuming step from our data acquisition routine. Overall, we estimated a ten-fold improvement was made to the PSP measurement technique.

Over the past year we have experienced significant slippage in our Research Agenda. A year ago, the next major milestone was a compressor test at the Compressor Research Facility (CRF). Unfortunately, the CRF experienced repeated obstacles that caused postponement of the test until late August 1999, over a year behind the original schedule. Details of this test are described below.

Compressor Test

Figure 27 shows a photograph of the test setup. The PSP system consists of a charge-coupled device (CCD) camera, a laser for illumination, a timing circuit to sync and freeze the blade motion, and the painted blades. In the photo you see the reference paint (pink), the pressure paint (yellow), and the temperature paint (white).

FIGURE 5. PSP Test Setup (ISP – Pink, TSP – White, PSP – Yellow).

Prior to PSP application, the engine-inlet surface was cleaned with alcohol and a lint-free cloth. The surrounding area was masked to prevent overspray. A white basecoat was applied and allowed to dry for about one hour prior to sol-gel deposition. Finally, registration (fiduciary) marks were drawn on the painted surface in a grid formation, and the precise locations were determined using a soldering gun and a coordinate mapping system (CMS). The soldering gun burned the paint locally so it would not luminesce. Hence, these points appeared as black spots in the data images. These control points allow reference images to be registered and accurately ratioed with the spatially distorted images acquired at test conditions. Data were acquired for all paints at 68% Nc and 85% Nc at both the near-stall and peak-efficiency operating conditions. Over-the-rotor kulite data and distortion data were also acquired relative to PSP data. All data is currently being processed and evaluated.

Participating Organizations: ISSI

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3.2.1.1 Pressure Sensitive Paint (PSP): Improved Dynamic Response

FY 97-98

Background: Characterizing the transient response of PSPs to unsteady pressure flows is a critical aspect in understanding HCF events. A group led by B. Carroll previously developed an apparatus capable of delivering a step change in pressure, and reported response times for proprietary PSP formulations tested on the order of one second. In previous work from our group, a pressure-jump apparatus was constructed and used to measure PSP response times on the order of one millisecond.

Recent Progress: A calibration chamber was constructed to quantify the dynamic-response characteristics of the PSPs. In this approach, continuous wave output (450 nm) from an array of 73-blue photodiodes is used to excite a PSP-coated coupon that is fixed within a calibration cell. The resulting luminescence is detected using a photodiode. Driving a 60-Watt piezoelectric speaker driver at frequencies ranging from 100 Hz to ca. 300 kHz modulates pressure within the cell. Comparison of the intensity modulation to the drive frequency determines the temporal response of the PSP.

Figure 28 presents preliminary high-frequency-response data for a sol-gel-based PSP (- - - -) and the associated speaker-drive function (——). Currently, design-configuration changes are being implemented to allow simultaneous acquisition of transducer and PSP data. This will provide data necessary to probe PSP high-frequency response based on phase-angle delays between drive and response signals. It is clear from these data, however, that the PSP is tracking the 0.2-psi pressure modulation (about ambient) at 5.7 kHz. Current efforts focus on increasing the frequency response of the sol-gel-based PSPs, while maintaining pressure sensitivity suitable for HCF-related applications.

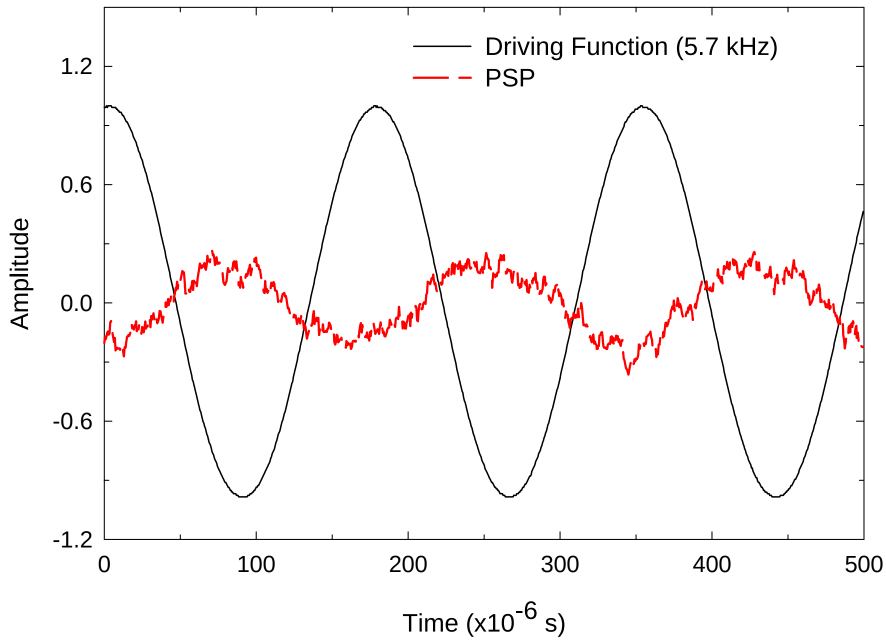

FIGURE 28. PSP Response to a 0.2-psi Pressure Modulation at 5.7 kHz

Future research efforts will focus on the development of an inorganic PSP. Through the synthesis of probe molecules, mechanisms that determine the temperature and pressure capabilities of the oxygen-sensing species used in PSPs can be controlled.

Participating Organizations: ISSI

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3.2.1.2 Pressure Sensitive Paint: Light Emitting Diodes (PSP-LEDs)

FY 99-00

Background: The objective of this task is to shed light on critical issues required to ensure that pressure-sensitive paints (PSPs) and thermographic phosphors (TPs) can be used in high cycle fatigue studies of turbomachinery. The critical issues to be addressed include probe miniaturization and paint/phosphor improvements.

Probe miniaturization requires the development of compact excitation and detection systems. Current excitation sources are heavier, bulkier, more labor-intensive, and costlier than those desired for certain Advanced Turbine Engine Gas Generator (ATEGG) and Joint Turbine Demonstrator Engine (JTDE) demonstrations. In this project, the use of high-power blue LEDs that hold promise for significant improvements in current methods of excitation for both PSPs and TPs will be investigated.

Pressure sensitive paint improvements in time response, survivability, and sensitivity at higher pressures and temperatures, and the use of thermographic phosphors as a means of temperature correction for the PSPs, are also being investigated.

Recent Progress: A prototype LED illumination system was developed and demonstrated in a recent engine test. This test was conducted with Pratt & Whitney through a Cooperative Research & Development Agreement. The deployment of PSP measurements in an engine test cell required two phases of setup: 1) model preparation and painting and 2) instrumentation installation and alignment. The following subsections summarize the steps taken to deploy PSP measurements within an engine test cell at Pratt & Whitney, East Hartford, Connecticut.

The internal diameter of the bell mouth tested was approximately 75 inches (1.9 m). The circular structure located upstream of the engine inlet (wagon wheel) was used to mount thermocouples. For this test, two symmetrical regions of the upper surface of the bell mouth were painted with a low-speed sol-gel-based PSP. A large quantity of data was acquired from this test, which was considered to be a success. Pratt & Whitney is now processing the data and writing a final report. This effort is scheduled to finish in the summer of 2000.

Participating Organizations: ISSI, Pratt & Whitney

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3.2.2 Comparison Testing/Air Etalons

FY 96-00

Background: The Air Etalon is a sensing concept based on Fabry-Perot interferometry. In its simplest form, a Fabry-Perot etalon consists of two mirrors separated by a certain distance, or gap. When light is incident upon an etalon, optical interference occurs; at certain optical resonance frequencies, virtually all of the incident light is transmitted through the etalon, while at other frequencies most of the light is reflected. The optical resonance frequency depends on the optical path length between the two mirrors—which of course is dependent upon the index of refraction of the material used in the gap between the two mirrors. This fact can thus be utilized to design a pressure sensor based on a Fabry-Perot etalon where the change in optical resonance is monitored as the optical path length changes as a result of changes in pressure. In this effort, both solid and air-gap etalons have been investigated as pressure sensors.

Recent Progress: In September 1999, we re-initiated our aerogel etalon pressure sensor effort, which had been hampered by funding problems. There are two key components of the program – fabrication of the aerogel sensors and measurement of their pressure sensitivity. For the fabrication component, we have identified a small company (NZ Applied Technologies) that is capable of coating aerogels with the requisite mechanical and geometric properties onto substrates. We have reached an agreement with them whereby they will do the required coating work for us in an iterative manner as we successively redesign the coating properties according to feedback from our measurements.

In order to accomplish rapid screening of the pressure sensitivity of fabricated devices, we have set up two experimental measurement systems. One system is capable of determining the transmission and reflection from an etalon as a function of optical wavelength and static pressure. This will be used for initial screening of etalon optical properties and static pressure sensitivity. The second laser-based system is capable of determining the transmission and reflection from an etalon at a fixed wavelength with fast time response. This will be used to assess the time response of the pressure signal from fabricated etalons that have passed the static pressure sensitivity screening tests.

In the coming months we will fabricate and test etalons according to the procedure outlined above. Task completion is projected for the summer of 2000.

Participating Organizations: Rolls Royce Allison, General Electric Corporate Research & Development

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3.2.3 Thin-Film Garnet

FY 99-01

Background: The objective of this project is twofold: (1) to investigate a new surface pressure-sensing concept, and (2) to develop a compact fluorescence detection system. The concept utilizes forester energy transfer, a process that can occur in conjunction with photoluminescence, and is very sensitive to the distance between an energy donor and an energy acceptor. Because of this spatial sensitivity, it has been exploited as a "molecular caliper." Under this effort, the use of Forester energy transfer to measure the surface pressure of the thin-film garnet is being investigated. In addition, a compact fluorescence detection system will be developed whose ideal application is the acquisition of data from either the thin-film garnet, pressure paint, or thermographic phosphor.

Recent Progress: Over the past year, we have explored the use of electronic energy transfer as a pressure transducer. We are looking for surface measurement capability in the range of 0.6 to 3 atm as an alternative to pressure-sensitive paint. The rate of electronic energy transfer, of the Förster type, is extremely sensitive to the distance between the energy donor and energy acceptor species, and it is this phenomenon that we exploit in the advance of new pressure-sensitive materials. The selection of the energy transfer species and the host matrix is guided by the operational requirements of temperature and pressure inside the engine; inorganic or atomic species embedded in a ceramic or glass-like host was our initial choice. The host material must be selected with care as the material must be reasonably compliant to respond to the operational pressures, yet be robust to withstand the operational temperatures and corrosive environment. Some oxide glasses or sol-gel compounds may be the best option.

A theoretical model has been established to show the relationship between the material properties and the sensor performance. The Cr^{+} - Nd^{3+} energy transfer system was identified as a potential pressure sensor. We continue to investigate host materials for optimal performance. Many host-material requirements have been identified such as acceptable Young's Modulus, and the material structure and orientation. The aerogel host matrix selected for the etalons described in Section 3.2.2 may also be well suited for this energy-transfer concept. Preliminary calculations show that this innovative technique has the potential to measure pressures in the desired range with a resolution of 0.029 atm.

Work continues in this area and is expected to be complete by March 2001.

Participating Organizations: TACAN Corp.

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3.2.4 Spin-Pit Validation of Paint/Optical Pressure Mapping

Recent Developments: This task has been redefined. An Advanced Turbine Engine Gas Generator (ATEGG) test will be conducted in fiscal year 2005 rather than a spin-pit test. We are currently working on the contract change to accommodate this task with the General Electric / Allison Advanced Development Company team.

Participating Organizations: Rolls Royce Allison, General Electric Corporate Research & Development, ISSI, TACAN

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3.3 Improved Conventional Sensors

To date, prediction of aerodynamic forcing functions has been difficult or impossible due to lack of Computational Fluid Dynamics (CFD) fidelity, structural modeling accuracy, instrumentation effects, and insufficient characterization of instrumentation installation effects. The purpose of the projects described below is to improve the lifetime and performance of conventional sensors (eddy current/strain gages) for transition into engine health monitoring applications.

3.3.1 Non-Optical NSMS Sensor Development (Eddy Current)
FY 99-01

Recent Progress: The eddy current sensor (ECS) was tested as part of the JSF Seeded Fault Engine Test Program at Pratt & Whitney in West Palm Beach, Florida in 1999. Under this program, two F100 engines with seeded faults were used to evaluate candidate prognostics and health management technologies (PHM) for future aircraft engines.

The ECS build 3 system was evaluated during this test. This system consisted of seven ECS sensors installed into the engine case over the first-stage fan, test cell based electronics, and personal computer (PC) data acquisition and processing. In the test, the ECS measured blade clearances, deflections, and speed. This data was used to estimate clearance closedown, blade vibration, and foreign object impacts. The testing was successful, and as a result, the ECS has been boarded on two stages of an engine currently under development. Figure 29 shows an example of the ECS vibration estimation for a second torsion mode on the first-stage fan driven by 21E. Figure 30 shows an example of clearance closedown for the same stage for all blades. Last, Figure 31 shows an example of foreign object impact, identified by blade number.

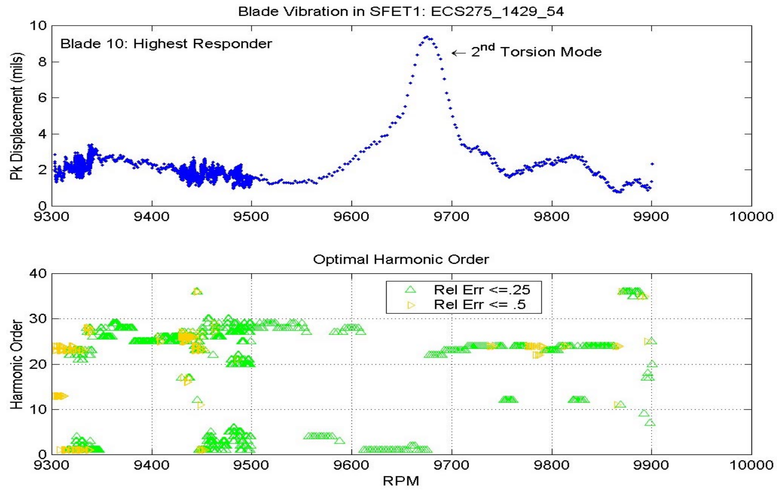

FIGURE 29. Eddy Current Sensor Vibration Estimate, Seeded Fault Engine Test (SFET#1), Blade 10, 2nd Torsion Mode

Later in the year, the ECS build 4 system was completed. This system has real-time processing and a sensor with a higher standoff capability that allows the sensor to be recessed into the engine case, below the rubstrip. This build 4 system will be tested in early 2000.

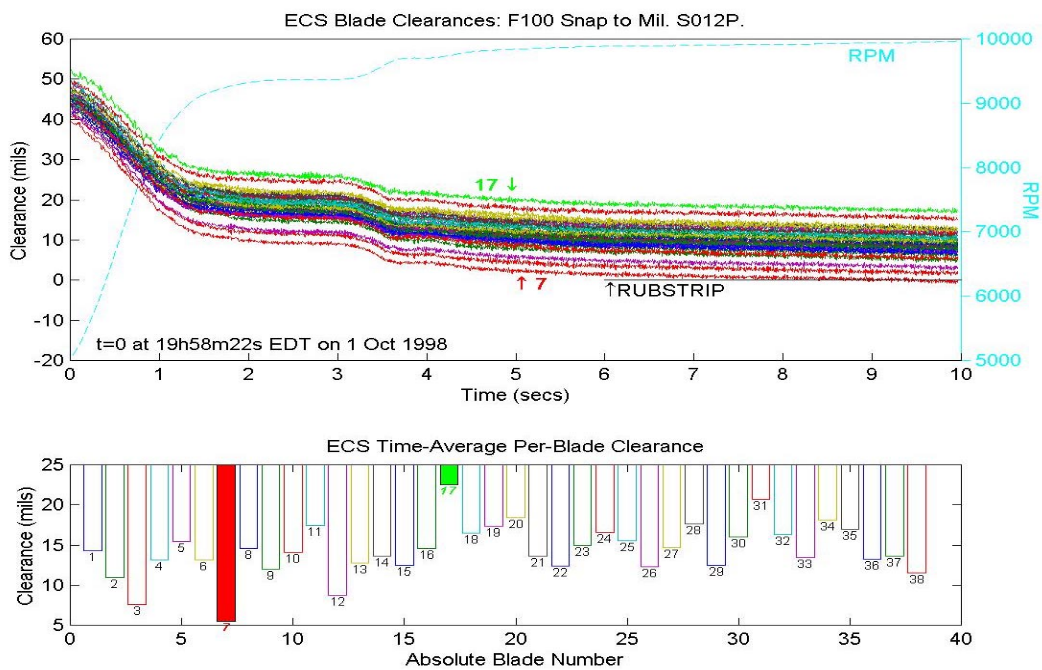

FIGURE 30. Eddy Current Sensor Clearance Closedown, SFET#1, All Blades Shown

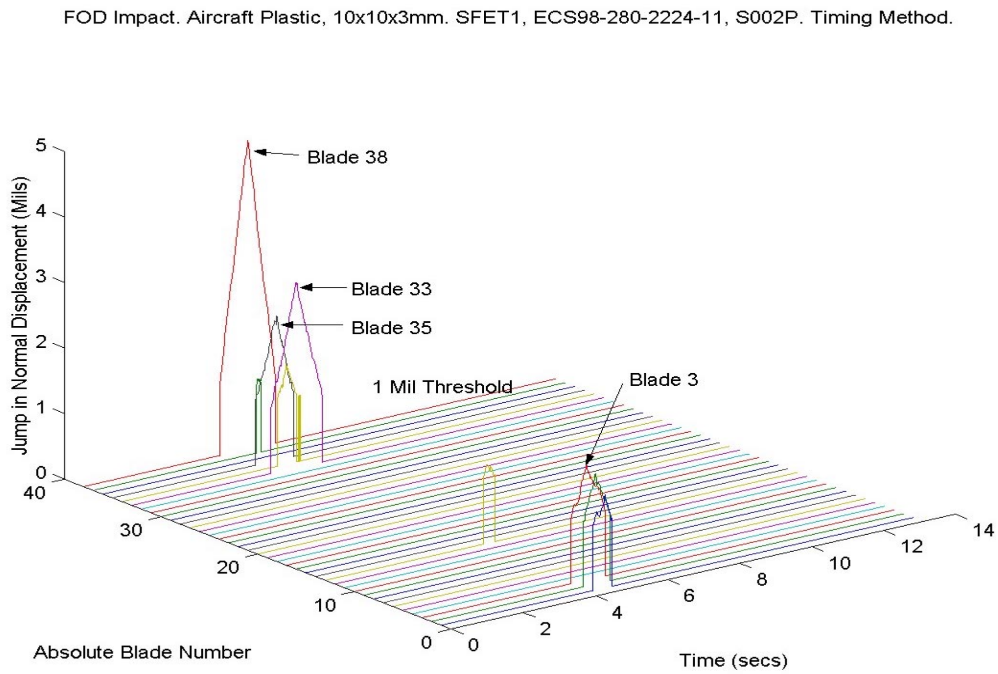

FIGURE 31. Eddy Current Sensor Foreign Object Impact Detection, SFET#1, Composite Material (10mm x 10mm x 3mm)

Participating Organizations: Pratt & Whitney

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3.4 Development of Long-Life, Less-Intrusive Strain Gages

The following sections describe NASA's efforts to develop long-life, less-intrusive strain gages.

3.4.1 Advanced Thin-Film Dynamic Gages

FY 95-01

Background: The objective of this program is to develop and utilize the already successful NASA PdCr static strain gages in a thin-film form for dynamic strain measurement. Thin-film sensors are fabricated directly onto the test surface using vapor deposition and lithography techniques. They do not require additional bonding agents such as adhesive or cements, and are in direct contact with the test surface. Thin-film sensors in general have a thickness on the order of a few micrometers (µm) which are much thinner than the commonly-used sensor wires. They have fast response times (in milliseconds), add negligible mass to the test surface, and create minimal disturbance of the gas flow over the surface. Consequently, thin-film sensors have minimal impact on the thermal, strain, and vibration patterns that exist in the operating environment, and provide a minimally intrusive means of accurate measurement of surface parameters.

Recent Progress: During the past year, the PdCr thin-film dynamic strain gages were fabricated on nickel-based superalloy and ceramic based cantilever bars. The dynamic response of these gages was characterized in a newly set up shaker facility under ±2,000 microstrain, 1,000 Hz to 700C. The lifetime of this PdCr-based thin-film gage were compared to the conventional foil strain gages at the room temperature. Only two of the six commercial foil gages (33%) survived after only 3.5 minutes dwell at 1,100 Hz, while all the PdCr gages (4) remained functional after 50 minutes dwell exposure. The test at high temperature was stopped due to the test bar cracking and breaking, although no gage delamination was found. Meanwhile, Honeywell Engines and Systems is applying these PdCr thin-film strain gages to the fourth-stage gamma blades of Pratt & Whitney demonstrator core XTC67/1. The engine test is scheduled for the fall of 2000. (See section 8.2.5.)

Participating Organizations: NASA Glenn Research Center, Honeywell Engines and Systems

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3.4.2 Advanced High-Temperature Thin-Film Dynamic Gages

FY 96-01

Background: The objective of this program is to develop advanced thin-film strain gages with increased temperature capability. This work is proceeding under a grant with the University of Rhode Island (URI) and is based on a ceramic sensing material, Indium Tin Oxide (ITO).

Recent Progress: During the past year, the characteristics of the ITO strain sensor were evaluated up to 1,450°C (2640°F). A reproducible piezoresistive response was measured with a drift rate as low as 0.0018%/hr at 1,450°C. The gage factor of the gage remained relatively constant from room temperature to 1,100°C with a maximum gage factor of 21.8 at 1,190°C (2,170°F). The dynamic response and lifetime of the gages were characterized in a shaker facility under ±300 microstrain, 2,100 Hz, to T=700°C. This ITO-based strain sensor failed after an 18 million cycle test at room temperature, five thermal cycles to 1,100°C, and then 11 million cycles at 700°C. The failure was due to the detachment of lead wires from the thin-film sensor.

Participating Organizations: NASA Glenn Research Center, University of Rhode Island

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3.4.3 Spin-Pit Validation of Strain Gages and Spin-Pit Validation of High-Temperature Strain Gages

Recent Developments: These two tasks have been eliminated, as the Pratt & Whitney XTC67/1 test will be sufficient to show the gage capability.

3.5 Conclusion

The Instrumentation Action Team demonstrated a 5x improvement in the accuracy of light probes—a major advancement in Non-Interference Stress Measurement System (NSMS) capability—and increased the dynamic response characteristics of Pressure Sensitive Paints (PSPs) by a factor of six. These characteristics are now adequate for many fan component applications. The light probe developed for the Gen IV NSMS outperforms current eddy current and capacitance probe technology. The advanced NSMS has been tested in flight on an F100 engine in an F-15 aircraft. Having the ability to validate vibratory responses during actual flight reduces the probability that HCF-susceptible blades will be placed in production. Out-year efforts are continuing to develop the technology necessary to effectively apply NSMS to small engines. Out-year efforts for PSP include the demonstration of high-response data acquisition.